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Atmospheric Transmission Measurements Using IR Lasers, Fourier Transform Spectroscopy, and Gas-Filter Correlation Techniques

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Atmospheric Transmission Measurements Using IR Lasers, Fourier Transform Spectroscopy, and Gas-Filter Correlation Techniques

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An extensive measurement system for atmospheric-transmission field experiments is described with emphasis on the recent additions of a high-resolution, scanning, Fourier-interferometer system and a gas-filter correlation spectrometer. Results obtained from three concurrent experiments used to generate a data base appropriate to high-resolution transmission model validation are displayed. Laser extinction data, high-resolution, long-path atmospheric transmission spectra, and path-integrated water vapor measurements are reported and discussed. Plans for future field experiments utilizing these three measurement techniques plus broadband infrared transmissometer and infrared target-signature measurement are discussed.

INTRODUCTION

For several years, NRL scientists have been conducting field experiments dealing with atmospheric propagation of infrared laser beams. Earlier experiments were designed to study the effects of beam spreading and beam wander caused by atmospheric turbulence (1-6). Recently, measurements of atmospheric extinction at several laser wavelengths of interest to the Navy High-Energy Laser Project—primarily those of the DF laser operating near 3.8 μm—have been emphasized.

During 1975, two extensive experiments were conducted at coastal sites in Florida (7) and later in California (8). The Florida experiment followed initial DF laser transmission measurements performed at the Cape Canaveral Air Force Station (CCAFS) early in 1974 (9,10). The California experiment was performed in conjunction with high-power, DF laser propagation tests conducted during the Joint Army-Navy Propagation Experiments at the TRW Capistrano Test Site during May through October 1975.

Several hundred measurements of DF and Nd-YAG laser transmission, along with supporting meteorological data, were used to test the validity of transmission predictions based on a line-by-line computer code calculation. The results of comparisons of the field measurements with predictions based on a HI-TRAN (11) type calculation using the AFGL spectral line atlas (12) as modified by Woods *et al.* (13,14) have been reported (8) and are summarized in this article's next section.

Recent modifications to the trailer-based measurement system used in the earlier Florida and California experiments included two significant additions: a high-resolution atmospheric measurement capability based on a Fourier transform spectrometer (FTS) system and a gas-filter correlation spectrometer (GFCS). Details concerning the facilities used in and the operation of the laser extinction, FTS, and GFCS experiments are presented in Reference (15).

The following sections outline the apparatus used in the three types of measurements, the philosophy underlying the experiments, the more important results obtained in recent studies, and experimental program plans for the near future.

LASER EXTINCTION MEASUREMENTS

Several trailers (shown in Figure 1) house the equipment used in these measurements. Infrared lasers, transfer optics, and a large (90-cm aperture) collimating telescope are located in an optical transmitter trailer (second from the right in Figure 1). The 75.5 m^3/s (1600 ft^3/min) vacuum pump required to operate the cw DF laser used in these experiments is housed in a separate "pump" trailer and connected to the laser system in the transmitter trailer by a demountable, 20-cm-diameter high-vacuum line, installed once the trailers are on site.

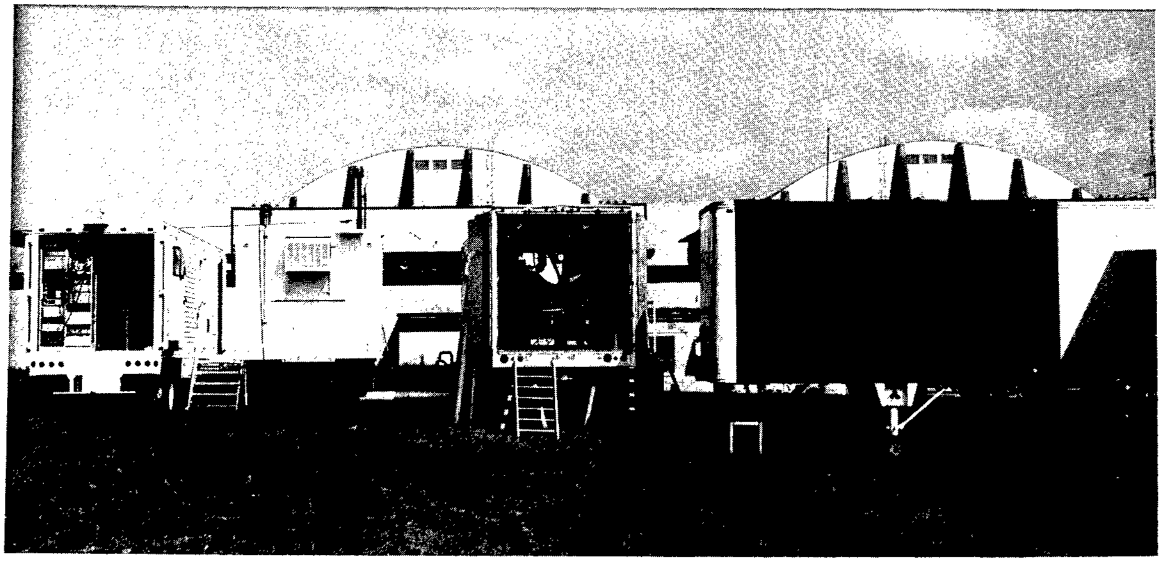

Figure 1—Transmitter station for Patuxent NAS experiments. From left to right: office trailer, pump trailer, transmitter trailer, supply trailer.

A third trailer contains a receiver optical system (not shown) with a 120-cm-diameter collecting mirror. Gas bottle storage and other supplies in a fourth trailer (far right) allow the operation of the experiments to be predominately self-contained.

Meteorological conditions at both ends of the experimental propagation path are monitored by two nearly identical sensor systems. Each system measures wind velocity and direction, dew point, atmospheric pressure, temperature, and isolation. One system also has an aerosol spectrometer which obtains ambient aerosol distributions and operates out of a meteorological/aerosol van (not shown). The other system is controlled from a fifth trailer (far left) which also contains office space.

Figure 2 illustrates the optical system contained in the transmitter trailer. The caption identifies the various components. By means of dichroic beam-combining plates, the HeNe and Nd-YAG laser beams are coaxially combined and then in turn coaxially combined with the output beam from either the HF/DF, CO, or CO_2 lasers. Each of these three infrared lasers is operated single line, Tem_{oo} mode, by using intercavity grating reflectors.

Laser sources, transfer optics, and a large collimating telescope are mounted as a unit in a massive frame which can be steered a few degrees in azimuth and elevation, with respect to a massive optical bench. This bench sits on piers which extend through the trailer floor to rest on solid ground, thus decoupling the telescope from the trailer body. This massive assembly has proven stable during several years of field use; the output beam can be reproducibly pointed and maintained in alignment over angular changes as small as 10^{-5} rad. Reference (15) details the DF laser system, optics, and supporting equipment.

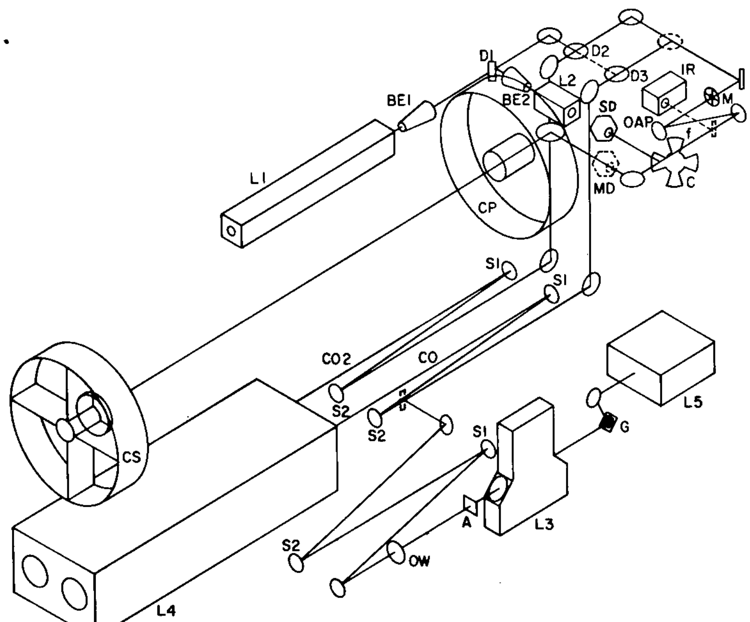

Figure 2—Transmitter optical schematic. L1—50mw HeNe laser, L2—0.25 watt Nd-YAG laser, L3—1w HF/DF laser, L4—20w CO_2/1w CO laser, L5—HeNe alignment laser, IR—greybody source, BE1-2—refracting beam expanders, D1—HeNe/Nd-YAG dichroic, D2—visible/CO_2 dichroic, D3—visible/HF/DF or CO dichroic, M—pupil mask, OAP—off axis parabolic mirror, C—37 Hz, 50% chopper, SD—stationary detector, MD—mobile detector (calibration), CP—Cassegrain primary, CS—Cassegrain secondary.

Figure 3 outlines the basic procedure used in the laser extinction measurements. As indicated, the off-axis parabolic mirror focuses the cw, coaxial laser beam to be transmitted which diverges to fill the pupil of the 90-cm Cassegrain telescope. The large aperture output beam is then focused at the receiver site—typically 5 km away. For moderate turbulence conditions, a 90-cm focused beam leaving the transmitter will have a 30- to 45-cm cross-sectional diameter at 5 km for $\lambda = 3.8\ \mu m$. As established both theoretically (16,17) and experimentally (5), turbulence-induced beam spreading is inversely proportional to some fractional power of wavelength (0.2 to 0.33). Visual observation that the beam is entirely collected by the 120-cm aperture receiver mirror ensures collection of the infrared laser beam distributions. Nearly perfect colinearity of the visible and infrared beams is achieved by alignment techniques which require simultaneous superposition of the two beams at two locations in the input optical train of the transmitter telescope.

The laser beam collected by the receiver mirror is focused onto a spatially integrating detector assembly by a combination of a small (1-cm diameter) Newtonian diagonal mirror and an ellipsoidal mirror. The "mobile" detector is normally positioned in the receiver optical system (at right of Figure 3), but can also be located immediately behind the primary mirror of the transmitter telescope (at left), for calibration measurements. Laser power is continuously monitored by a stationary, reference detector by using that portion of the beam reflected by the 50% duty cycle, 37 Hz chopper.

Periodically, the transmitter and receiver trailers are placed end-to-end (in a "zero path" configuration) for calibration of the optical system efficiency of the large transmitter telescope components and the receiver optics. This efficiency factor is required in order to obtain actual atmospheric transmission.

The signal received by the mobile detector in the receiver trailer is relayed to a precision ratiometer in the transmitter trailer by a GaAs data link (bottom of Figure 3). Thus atmospheric extinction can be obtained in real time, once the detector relative response and transmitter-receiver optical system efficiencies

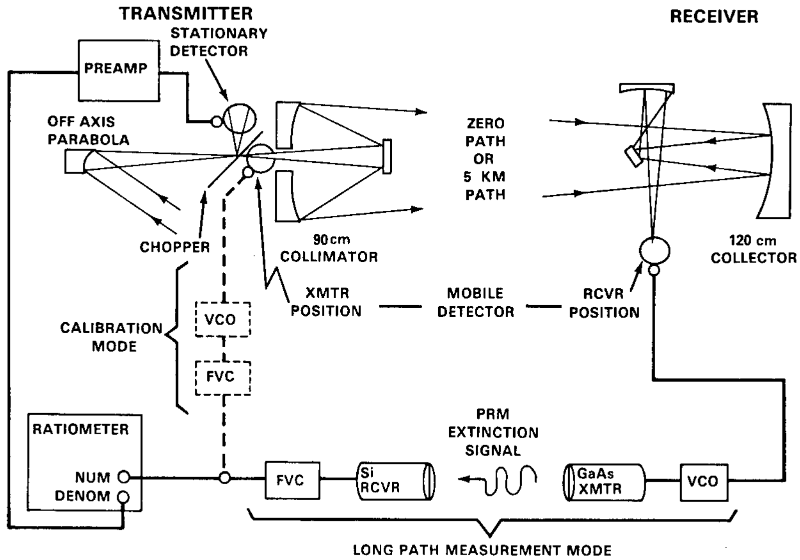

Figure 3—Laser extinction measurement schematic. VCO—voltage controlled oscillator, FVC—frequency to voltage converter, PRM—pulse rate modulated (extinction signal).

are known. Reference (15) contains additional details concerning the design and operation of this measurement system.

Rationale

Laser extinction measurements performed in previous experiments (7,8) have been used in comparisons with molecular absorption predictions based on a HI-TRAN calculation (11) which uses the AFGL spectral line atlas (12). This work's principal objective has been to develop a reliable predictor for atmospheric transmission at DF laser frequencies. Certain improvements in HDO spectral line strengths, which resulted in this process (13,14), came via contractual support from Science Appl. Inc., Ann Arbor, Michigan.

Future laser extinction experiments will extend the results obtained in the DF region to the CO and CO_2 laser regions and will also provide a basis for absolute transmission calibration of high-resolution atmospheric absorption spectra taken with the FTS system described below.

Results

A comparison between observed extinction (which includes aerosol scattering effects) and calculated molecular absorption for 22 DF laser lines between 3.6 and 4.1 μm is shown in Figure 4. One would expect a constant offset between the two sets of points, due to aerosol scattering. As seen in the figure, the agreement is quite good when the trends between the two sets of points are compared.

Data from both the Florida (7) and California (8) experiments, such as that in Figure 4, were corrected for aerosol effects (18) and compared with molecular absorption calculations. An example of such a comparison for the P1-8 DF laser line is shown in Figure 5, and a summary of such comparisons is presented in Table 1, for the midlatitude-summer water-vapor partial pressure of 1.9 kPa (14.26 Torr). Column five of the table lists the differences between measured and calculated absorption coefficients for each of the DF laser lines listed in column one. The calculations utilized new HDO line strengths and widths (13,14), and the agreements between theory and field measurements are quite good, with the worst case differences remaining about 20%.

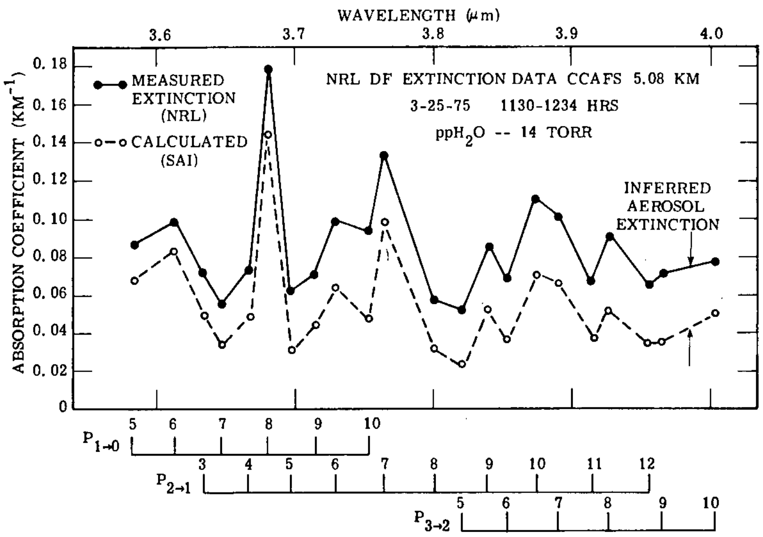

Figure 4—Comparison of calculated molecular absorption (○) with field measurements (●) of DF laser extinction

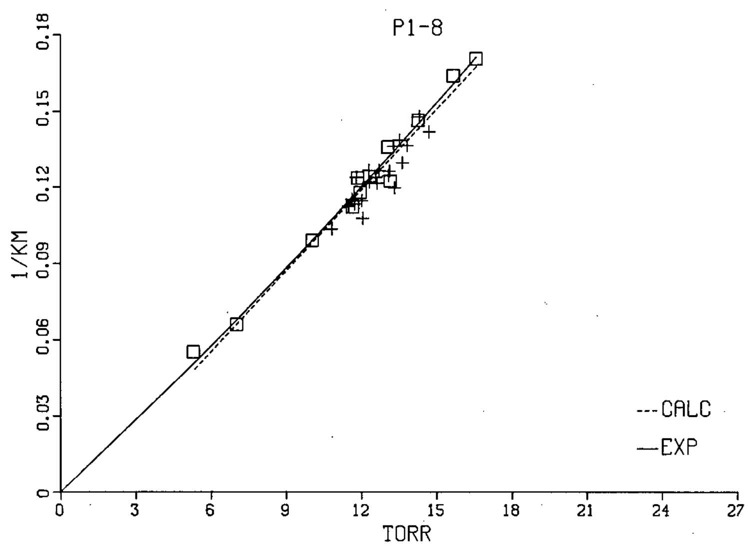

Figure 5—Comparison of measured and calculated molecular absorption for the P1-8 DF laser line *vs* water vapor partial pressure. □ = Measurements taken at Cape Canaveral Air Force Station, Florida, March 1975, + = measurements taken at the TRW Capistrano Test Site, September 1975, ——— curve fit to experimental data, ------ curve fit to HI-TRAN calculations.

Table 1
Comparison of Measured and Calculated Molecular Absorption for Midlatitude Summer Conditions
(14.26 Torr Partial Pressure H_2O)

Line	Position (cm^{-1})	α (km^{-1})		(Exp-Cal)/Cal (% diff)	$\sigma_{exp/cal}$ (%)
		Exp	Cal		
P3(10)	2496.721	.0516	.0514	.4	4.7
P3(9)	2521.769	.0364	.0366	−.5	12.5
P2(12)	2527.391	.0340	.0346	−1.7	4.0
P3(8)	2546.375	.0561	.0511	9.9	9.3
P2(11)	2553.952	.0360	.0365	−1.3	16.0
P3(7)	2570.522	.0701	.0648	8.2	5.7
P2(10)	2580.096	.0736	.0678	8.7	17.7
P3(6)	2594.197	.0364	.0308	18.1	8.8
P2(9)	2605.806	.0554	.0513	8.0	16.2
P3(5)	2617.386	.0221	.0229	−3.5	10.7
P2(8)	2631.067	.0302	.0360	−16.0	13.3
P2(7)	2655.863	.1023	.1004	1.8	4.4
P1(10)	2665.219	.0460	.0381	20.5	16.7
P2(6)	2680.179	.0639	.0600	6.6	7.2
P1(9)	2691.606	.0435	.0463	−6.1	6.9
P2(5)	2703.999	.0284	.0300	−5.3	12.0
P1(8)	2717.538	.1456	.1437	1.3	2.5
P2(4)	2727.309	.0437	.0574	−23.8	4.5
P1(7)	2742.997	.0311	.0350	−11.1	12.3
P2(3)	2750.094	.0457	.0425	7.6	11.9
P1(6)	2767.968	.0764	.0876	−12.3	8.1
P1(5)	2792.434	.0661	.0705	−6.3	9.6

FOURIER TRANSFORM SPECTROSCOPY (FTS) MEASUREMENTS

An FTS system based on a scanning Michelson interferometer (SMI) is now used for high-resolution atmospheric transmission studies. This instrument, as well as the GFCS device mentioned earlier, uses the receiver optical system shown in Figure 6. The primary collector (P1) is a 120-cm-diameter, f/5 parabolic mirror which forms a Newtonian telescope with the small (1-cm minor diameter) diagonal mirror (F1). The beam reflected from F1 passes through a focus (f1) and then impinges on the elliptical mirror (E) which refocuses the beam outside the entrance pupil of P1.

For extinction measurements, the mobile detector (MD) is placed near the secondary focus (f2) of the mirror E. For SMI or GFCS experiments, MD is removed, and the beam passes through f2 and is re-collimated with a 5-cm-diameter cross section by the parabolic mirror (P2) and then directed by flat transfer optics into either the SMI or GFCS instruments. The optics and spectrometer instruments are housed in two separate rooms in the receiver trailer. A third room houses the data processing system for the SMI device. Reference (15) gives a detailed description of this instrumentation.

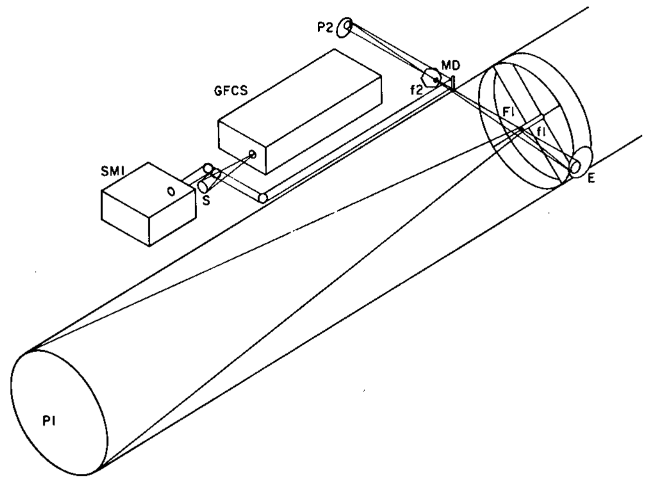

Figure 6–Receiver optical system. P1–120-cm diameter, f/5 parabolic mirror, F1–1-cm minor diameter elliptical diagonal secondary mirror, f1–location of focal point of P1, E–ellipsoidal relay mirror, MD–mobile detector, P2–recollimating parabolic mirror, SMI–Scanning Michelson Interferometer, GFCS–gas filter correlation spectrometer.

The SMI data system controls the SMI scan length and rate and performs interferogram coaddition and fast Fourier transformation (FFT). To achieve a spectral resolution of 0.06 cm^{-1} over the interval from 1.3 to 6.0 μm, a 256 000-point double-precision (32-bit) FFT must be processed. The present data system, which utilizes a hardware FFT processor and 10^7 byte (8-bit) disc drive, can accomplish this procedure in less than 10 minutes. A digital tape drive is used with the system to record observed spectra and an electrostatic plotter is used for graphical presentation. The SMI system was designed and built by the Carson Alexiou Corp., Newport Beach, California.

Rationale

The objective of the FTS measurements is to generate an extensive experimental data base for use in HI-TRAN code validations. The comparisons of DF laser transmission measurements and codes described earlier proved useful in identifying discrepancies between calculated and measured molecular line-absorption features. Relatively wavelength independent and weak absorption features due to molecular continua (N_2 and H_2O in the DF laser region) are not as readily identified by means of the laser-line-measurement HI-TRAN code comparison procedure. The FTS data provide a one-to-one map of a spectral region for comparison with calculation, as opposed to a comparison carried out only at several frequencies (*e.g.* 22 laser line positions between 3.6 and 4.1 μm in the DF laser region).

Once high-resolution spectra are obtained and an absolute transmission calibration is derived from laser extinction measurements throughout the observed region, the measured transmission spectra can be numerically degraded as required, in order to make comparisons with infrared systems which operate in finite spectral bands. These include most current E-O devices such as IR seekers, FLIRS, IR transmissometers, and the like. The correct starting point for modeling atmospheric transmission values for such comparisons is a properly calibrated HI-TRAN code. Low-resolution calculations which may not adequately represent the details of actual atmospheric absorption structure can give erroneous results when convolved with the bandpass characteristics of a particular system. The narrower the operating band of the system, the greater the potential for such problems. Such ambiquities are eliminated by highly resolved spectral information for both the system bandpass and the atmosphere.

An example of these procedures is presented in Reference (19) which gives preliminary results representative of comparisons of high-resolution data to the response of a banded system. This comparison should be repeated for a wide variety of transmission values, using structured as well as clear spectral regions, to evaluate the response of the particular system under test to a variety of transmission conditions.

Results

The procedure used in calibrating the relative FTS transmission spectra by means of measured laser-line extinctions is illustrated graphically in Figure 7. The upper portion shows a transmission spectrum recorded at NATC, Patuxent River, Maryland, for the conditions listed in the figure. The lower portion shows the SMI response to the P1-8 DF laser line at 2717.538 cm^{-1}. By use of the procedures outlined earlier, a 51% transmission was measured at this line and used to calibrate the FTS spectra shown. The traces in Figure 7 are copies of records produced by the FTS data system plotter and show actual signal-to-noise ratios observed in the 5-km transmission spectra.

Figures 8 and 9 show recent results obtained with the FTS system by use of several DF laser transmission-calibration points. The lower portion of each figure shows a calculation of molecular absorption for the conditions listed above the plot. The calculations employ the same HI-TRAN code used in the DF laser line calculations discussed earlier (13,14). The overall agreement with measurement is remarkably good, although the calculation does indicate larger line strengths for some of the weaker absorption lines near 2500 cm^{-1}.

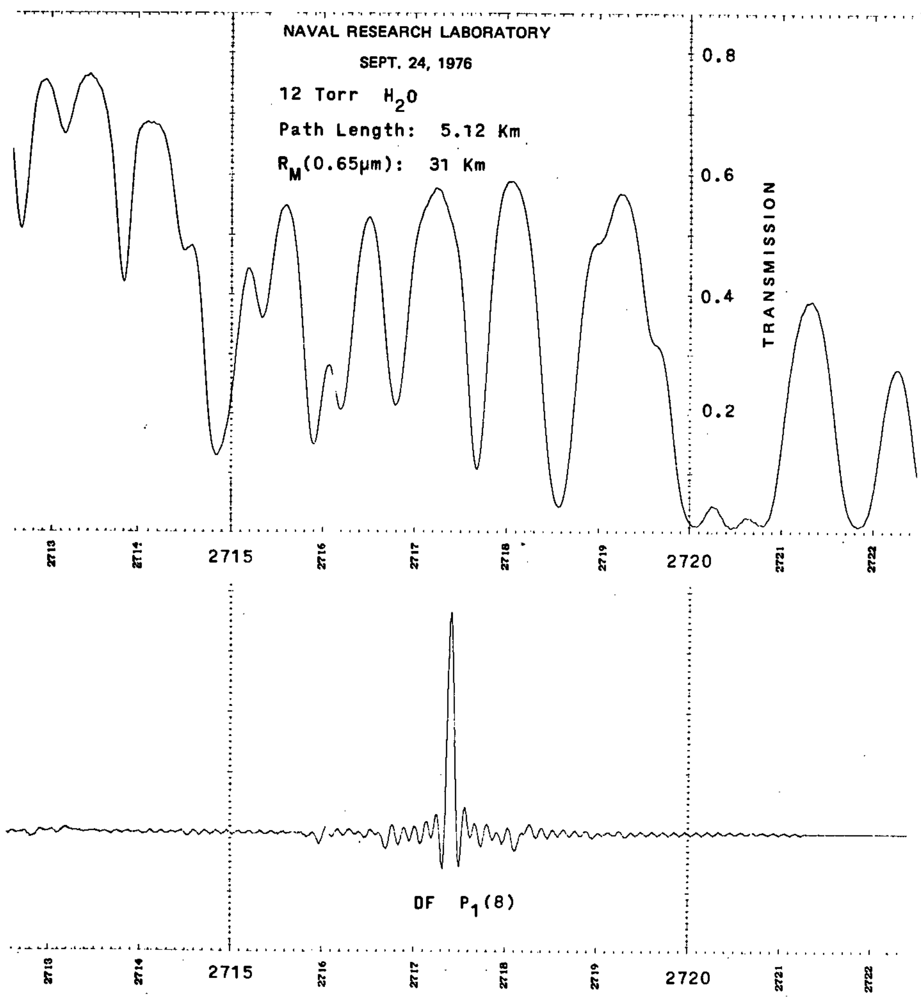

Figure 7—SMI spectra near 2720 cm^{-1}. Upper trace—experimental measured transmission of a 5.12-km path for 12 Torr H_2O and a visual range at 0.65 μm of 31 km. (Actual data trace); lower trace—SMI response to the P1-8 DF laser line at 2717.538 cm^{-1}. The measured laser transmission was .51, under the above conditions, and the upper trace was normalized to this value at the laser frequency.

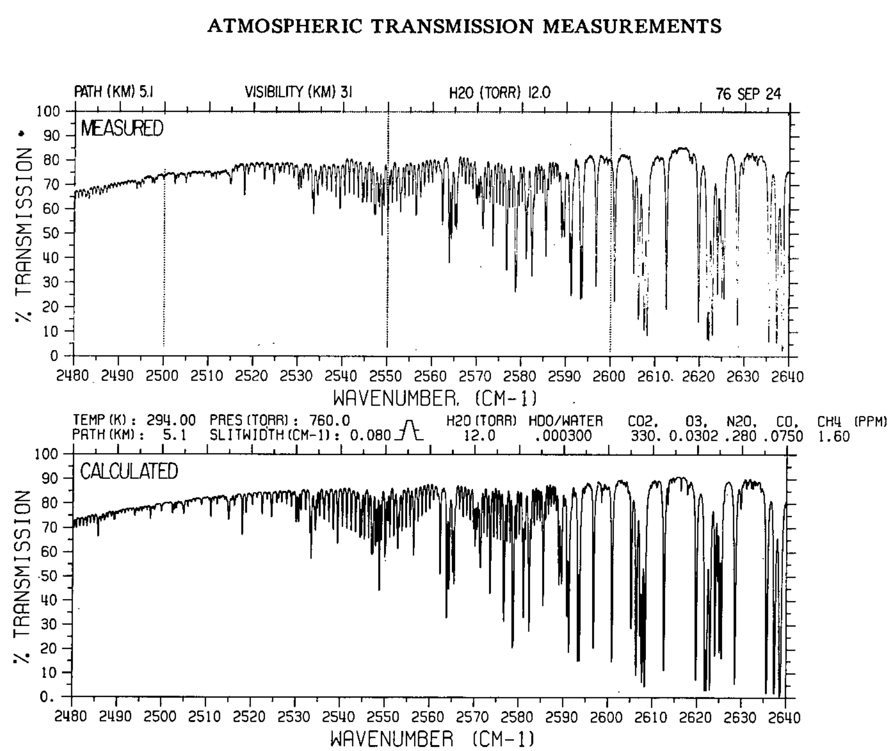

Figure 8—Comparison of measured and calculated atmospheric transmission spectra in the 2480-2640 cm^{-1} spectral region. Upper trace-measured transmission for 12 Torr H_2O, 5.1-km path length and 31-km visual range (2% contrast at 0.65 μm); lower trace-calculated molecular absorption (11-14) for conditions indicated above the trace.

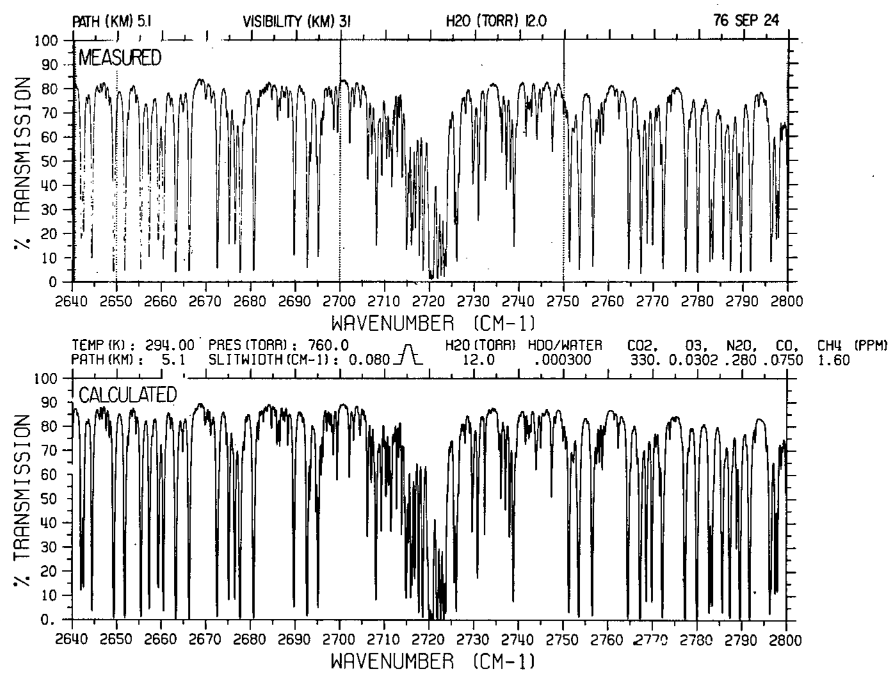

Figure 9—Comparison of measured and calculated atmospheric transmission spectra in the 2640-2800 cm^{-1} spectral region. Upper trace-measured transmission for 12 Torr H_2O, 5.1-km path length and 31-km visual range (2% contrast at 0.65 μm); lower trace-calculated molecular absorption (11-14) for conditions indicated above the trace.

Future laser-FTS measurements will include similar comparisons for a wide variety of atmospheric conditions and for other spectral regions. notably 4.8 to 5 μm and 9 to 11 μm, using CO and CO_2 laser extinction measurements, respectively, for absolute transmission calibrations.

GAS-FILTER CORRELATION SPECTROMETER (GFCS) EXPERIMENTS

The receiver optical system in Figure 6 is used for both SMI and GFCS measurements. In Figure 6, the 5-cm diameter beam recollimated by mirror P2 is directed into either instrument by means of a removable flat mirror. Figure 10 illustrates the basic operation of the GFCS device. The average transmission of an atmospheric constituent in the spectral interval $\Delta\nu$ is given by the expression equated to T_a. The energy from a greybody source, spectrally modulated by absorption due to one or more atmospheric constituents, is collected by the receiver optical system. This selectively transmitted energy is alternately passed through a spectrally nonselective attenuation arm with transmission T_R or through a cell containing a known amount of the absorber under study, whose transmission is $T_c(\nu)$. The nonselective transmission (T_R) is initially balanced against the average transmission of the cell during calibration. If the spectral character of the atmospherically transmitted energy resembles that of the cell absorber $T_c(\nu)$, then a difference in transmission and hence a modulation signal will result when the light from the distant source is alternately passed through the GFCS instrument's two arms.

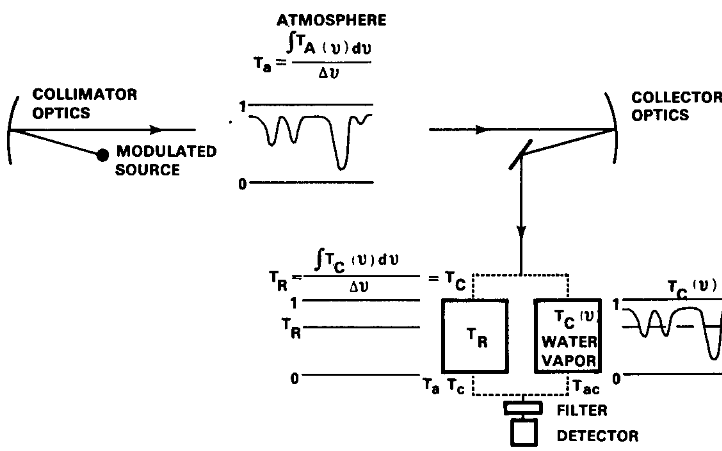

Figure 10—Gas filter correlation spectrometer measurement schematic

In these experiments the reference cell contained a known amount of HDO, and the purpose was to determine the amount of HDO absorption in the atmosphere.

Rationale

If the atmospheric abundance of HDO along the 5-km path used for the laser extinction and SMI measurements is measured by means of the GFCS, then a path integral value for atmospheric water vapor may be obtained by using the isotopic abundance of HDO/H_2O of 0.030% (12). Since water vapor is an important absorber in the infrared regions of interest for atmospheric transmission studies, this path integral is very important for use in comparisons of transmission data to calculational models. Path integral measurements, like those provided by the GFCS, are particularly useful for overwater transmission experiments where midpoints along the path are not readily accessible to standard dew-point observations.

The GFCS measurement cannot utilize normal water vapor as the filter gas, because an amount of water in a 5-km path at standard conditions cannot be maintained in the vapor state in the local reference cell. However, there is very little HDO in the atmosphere, so that a greatly enchanced concentration of that vapor can be held in a multipass absorption cell. A 5-km path equivalent amount of HDO is contained in the GFCS multipass reference cell, which affords a total path of 40 m.

Results

Figure 11 is a plot of data taken during recent experiments at the Patuxent Naval Air Station, comparing water vapor measurements obtained with the GFCS and EG&G model 110 dew-point hygrometers located on shore at each end of the 5.12-km overwater path. When an HDO/H_2O ratio of 3×10^{-4} is used in reducing the GFCS data, the results are consistently lower than the fixed point measurements, by ~30%. Further analysis, utilizing high-resolution spectra (such as that shown in Figures 8 and 9) is being pursued to resolve this apparent discrepancy. Independent HDO/H_2O ratios will be derived (from spectra taken during the GFCS measurements) by using measurements of individual H_2O and HDO spectral lines, together with recent line strength data (13,14). The possibility that the 3×10^{-4} abundance ratio cannot be universally applied to all sea level locations is quite important since the HDO/H_2O ratio profoundly affects DF laser propagation.

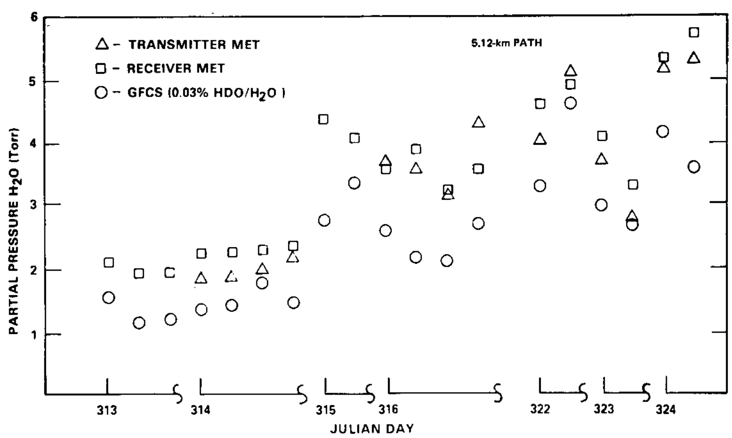

Figure 11—Comparison of gas filter correlation spectrometer and fixed point water vapor measurements

PLANS FOR THE NEAR FUTURE

An in-depth, atmospheric transmission measurement, experimental field program is planned for February to April 1977. Based on an evaluation of earlier test results, a propagation range at the Cape Canaveral Air Force Station (CCAFS), Cape Canaveral, Florida, has been selected. Both 5.1- and 3.2-km overwater paths are available, and large variations in absolute humidity (0.67 to 2.67 kPa (5 to 20 Torr) H_2O partial pressure) were observed during a February to March 1975 measurements program at this site. In addition, aerosol distributions typical of open ocean conditions were measured for easterly winds blowing across the measurement path from the Atlantic Ocean. A combination of factors including good site access, relative proximity to NRL, and excellent range support provided by the Naval Ordnance Test Unit (NOTU) and the Air Force Eastern Test Range (AFETR), as well as anticipation of very desirable meteorological conditions, make this location a compelling choice.

Laser extinction measurements with Nd-YAG, DF, short-wavelength (4.8-to 5.1-μm) CO, and CO_2 laser sources will be performed to explore (a) laser line propagation algorithm development and (b) high-resolution transmission spectrum calibration. GFCS data will be taken simultaneously and extensive meteorological data will be collected by fixed stations at each end of the transmission path and by a movable, intermediate station. A current measurement objective calls for simultaneous dew-point and aerosol distribution characterizations at two locations, in an attempt to better define the homogeneity of conditions along the propagation path. Details of the NRL aerosol measurement system and capabilities are presented in Reference (20).

In addition to addressing the principal objective of HI-TRAN code validation, the CCAFS experiments will provide an ideal theater for extension of the transmissometer system evaluation begun during the Patuxent tests. A transmissometer system, similar to the one described in Reference (19), is scheduled for delivery to the Naval Weapons Center (NWC), China Lake, for use by the Optical Signatures Program (OSP). Simultaneous experiments with the NRL laser-calibrated, high-resolution transmission measurements and the OSP transmissometer system are now being planned. Such measurements, under a wide variety of conditions, will significantly improve the understanding of the transmissometer's operating characteristics and should result in enhanced reliability.

A high-resolution, infrared-target-signatures measurement program utilizing the NRL-FTS capability will be evaluated for execution sometime after the CCAFS experiments. Several high-resolution (<0.1 cm^{-1}) emission spectra from Navy jet aircraft operating at NATC, Patuxent River were obtained during the transmission test just described. High-signal/noise, high-quality emission spectra obtained over a 5-km path by using the system described earlier demonstrate the feasibility of using the NRL system for a long-path, target-signature measurement program.

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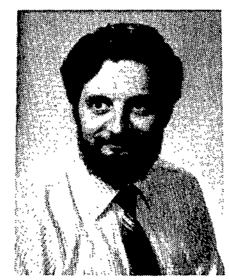
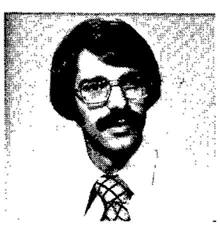
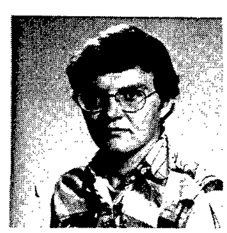


JAMES A. DOWLING received his Ph.D. in molecular spectroscopy from the Catholic University of America in 1967. He then joined the AVCO Space Systems Division in Lowell, Mass. There he performed research in optical communications, mechanically driven light sources for laser pumping, and high-speed spectrometry. Since joining NRL in 1969, Dr. Dowling conducted original research in atmospheric effects upon light propagation. He is responsible for the design and direction of several large field experiments concerned with studies of the effects of atmospheric turbulence upon focused laser-beam propagation, and more recently, with atmospheric transmission at infrared wavelengths. As head of the Linear Propagation Section of the Optical Radiation Branch, Dr. Dowling recently directed three large field experiments in Florida and California, which experimentally verified DF laser extinction models important to the Navy High-Energy Laser Program. He currently heads a research team engaged in measurements and computer modeling of infrared laser transmission, high-resolution Fourier transform and gas-filter correlation spectroscopy of the atmosphere, and high-resolution infrared-target signature studies.



KENNETH M. HAUGHT obtained his Ph.D. in physics in 1975 from the Ohio State University. His activities there centered on the design and construction of a 6-m vacuum infrared spectrometer used for high-resolution spectroscopic studies of various atmospheric constituents. Since joining the NRL Optical Sciences Division in 1976, he has worked in the atmospheric-transmission field measurements program. Since starting on this program, Dr. Haught has developed extensive computer software used in the analysis of infrared laser transmission and meteorological data. He recently carried out high-resolution atmospheric transmission experiments by use of an FTS system.



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STEPHEN T. HANLEY did his undergraduate and graduate work at the University of Washington. He obtained his Ph.D. in physics in 1973, while working on laboratory measurements of rate constants for upper atmosphere processes. He participated in the NRL Select Graduate Student Training Program, working in areas of space object surveillance and computer solution of heat conduction in three dimensions. In 1973, he joined NRL and worked on beam quality characterization and gas mixture analysis for the Navy Tri-Service Laser (NTSL). He also designed and installed a computer-controlled real-time data acquisition system for processing experiments conducted on the NTSL. In 1976, he joined the Optical Radiation Branch and has recently worked in the field measurements program, carrying out research in the near and middle infrared, by use of gas-filter correlation spectroscopy. Dr. Hanley is also performing synthetic, high-resolution, atmospheric transmission calculations used in the analysis of field measurements.

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WILLIAM L. AGAMBAR is a graduate of the Baltimore Institute of Electronics (1959). He was subsequently engaged in the design and production of communications and instrument landing instrumentation at Kinn Electronics Corporation. Prior to joining NRL-CBD in 1974, Mr. Agambar was self-employed as a building contractor. Mr. Agambar joined Science Applications, Inc. in 1975 and currently is with Potomac Research, Inc. Since 1974, Mr. Agambar worked with the field measurements team, providing logistical support and technical assistance in the operation of meteorological instrumentation and the collection and reduction of visibility data.